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RADIUM

EDITED BY
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AND
WILLIAM H. CAMERON, M. D.

VOL. XVI JANUARY, 1921 No. 4

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A MONTHLY JOURNAL DEVOTED TO THE CHEMISTRY PHYSICS AND THERAPEUTICS OF RADIUM AND RADIO-ACTIVE SUBSTANCES

RADIUM

A MONTHLY JOURNAL DEVOTED TO THE CHEMISTRY, PHYSICS AND THERAPEUTICS OF RADIUM AND RADIO-ACTIVE SUBSTANCES

Edited and Published by Charles H. Viol, Ph. D., and William H. Cameron, M. D. with the assistance of collaborators working in the fields of Radiochemistry, Radioactivity and Radiumtherapy.

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VOL. XVI JANUARY, 1921 No. 4

REVIEWS AND ABSTRACTS

William P. Graves, M. D. (Boston). Radium Treatment of Non-Malignant Uterine Bleeding. Some Immediate After-Effects. N. Y. Med. J. June 5, 1920.

"The value of radium in the treatment of non-malignant uterine bleeding has become so well established as to quiet all possible opposition. In fact it may be regarded as one of the greatest boons that has befallen the science of gynecology, both from the viewpoint of the patient, and from that of the distracted surgeon hesitating to perform a radical operation in the presence of some intractable hemorrhage. On the other hand, the amazing constancy and effectiveness its results, has imparted to the treatment a sort of magical glamor, especially among the laity, so that when patients encounter some of the unpleasant immediate after-effects that radium is prone to cause, they are often thrown into a state of keen disappointment and sometimes of serious depression."

"The object of this paper is to recount certain disagreeable sequalæ from intrauterine radiation which though mentioned by several writers have received minor attention or have been lost sight of in the reports of brilliant end results. Some of these symptoms are significant chiefly from the psychological influence which they may exert on the patient, but even these, as I shall show, may be of considerable import to the patient's general welfare."

"NAUSEA. First among the specific symptoms from an intrauterine application of radium must be mentioned nausea. This symptom is casually alluded to by a few observers. J. G. Clark refers to it, but says that "nausea and vomiting are the exception rather than the rule after radiation," and in no case has he seen the symptoms alarming or persistent. My own experience has been rather the reverse, for I find that the

majority of patients suffer more nausea than would be expected after a simple ether examination and curettage, in which the length of anesthesia would be approximately the same. That the nausea is due to something more than the simple effects of the anesthetic is often strikingly evidenced by the almost immediate relief that follows the removal of the radium in certain cases. In other cases the nausea has been persistent, with greater or less intensity, for a period much longer than is seen in even unfavorable cases after a short anesthesia, where radium has not been used. In some cases there is little or no nausea after radiation, but in my experience these cases are the exception, whereas after a simple curretting they are the rule. In one of my patients violent nausea and vomiting persisted for seven days after a mild dose. The patient, a strong young woman of twenty-seven, was neurotic and apprehensive, but the severity of the symptoms could not be explained wholly by her mental attitude, nor by the small amount of ether adminstered at the operation."

"We are accustomed to initiate the anesthesia with nitrous oxide, and to continue with enough ether for complete relaxation. This, when administered by an expert, is insignificant in amount, as the pelvic examination, dilatation, curettage, and application of radium require only a few minutes. The cause of the unusual nausea is not entirely clear. Possibly it may be explained as a sympathetic reflex from a foreign body inside the uterus, but the symptom, in my recollection, does not seem to have been particularly noticeable after the insertion of stem pessaries, or after the old fashioned practice of intrauterine drains and packs following curettage. Though the nausea following radiation is not a serious matter, it is often disconcerting to the patient who, with her preconceived notion of the magical simpleness of the radium treatment, has been anticipating an easy time of it. With the realization that most gynecological patients dread the anesthesia and its effects more than the operation itself, it should be made a routine practice to warn the patient that she is likely to experience more nausea than is to be expected after an ordinary operation of so short a duration. With such a forewarning, if unusual nausea does ensue, there is less chance of awakening the sense of disappointment and resentment which, as we shall see, may be the starting point of a train of nervous symptoms that may seriously impair the patient's health and happiness until the time when the full benefit of the radium treatment shall have been consummated."

"Bleeding. A second important afterresult of the radium treatment is a possible continuation or reappearance of the bleeding, for the cure of which the operation was undertaken. Such bleeding may appear within a few hours after the removal of the radium, and may persist for days or sometimes weeks, with varying degrees of intensity and constancy, before permanent cessation takes place. The amount of blood lost varies from a steady profuse flow to an occasional scanty showing, and the time of its appearance mey extend from two or three days to five or six weeks. To a nervous, apprehensive woman, not premonished of this possible event, and confidently expectant of an instantaneous cure, the continuation of symptoms comes as an alarming shock, and the attendant who has neglected to forewarn his patient finds it extremely difficult to explain the condition. In some case, in patients treated for menorrhagia, the next one or two periods may show no diminution, and sometimes even an increase of the catamenial flow. Here again the attendant who has not cautioned his patient finds himself in an embarrassing predicament in his perfectly truthful assurance that the ultimate

result will probably be entirely satisfactory."

"The recurrence of bleeding is one of the difficult problems in radiation for nonmalignant uterine hemorrhage. Its proper solution will involve the consideration of numerous factors, such as the character of the endometrium and myometrium, the amount and length of the dose, the choice of time for treatment, the constitutional idiosyncrasies of the patient, with special reference to vascular lesions, to the endocrine glands, and other factors. I have encountered troublesome afterbleeding most commonly in women with myomatous uteri. There were two serious cases of protracted hemorrhage in patients with moderately large fibroids, radical operation being contraindicated on account of dangerous hear tlesions. One of these patients eventually became entirely well, with an extraordinary diminution of the myomatous growth. The other patient came later to operation, and died during convalescence from a pulmonary embolism."

"LEUCORRHEA. A third specific aftereffect of intrauterine radiation is leucorrhea. In cases of recurrent bleeding it seems to appear as the end result of the flow in the form of a thin watery discharge of a pinkish hue which gradually fades to a pale brown or colorless character. In cases where the radium application has caused a complete cessation of bleeding the same watery discharge usually ensues for a varying length of time, lasting from a few days to several weeks or months. Some patients do not notice it at all, but they are in the minority. It has been a matter of rather frequent personal observation that this characteristic radium leucorrhea appears periodically for several months at the usual menstrual time and seems to indicate an effort on the part of nature to re-establish the menstrual rhythm. The discharge is chemically irritating and if not properly treated by cleansing douches becomes foul and may set up an annoying vaginitis, as has occurred in more than one of my cases."

"The origin of the discharge has, so far as I know, not been definitely determined. Its source seems to be from the endometrium. It may represent a superficial necrosis of the mucous membrane, or it may result from stimulation of the endometrial glands; probably both factors share in the process."

"The specific leucorrhea following radiation has been alluded to by several writers as of little importance, and indeed in the majority of cases such is the fact. Nevertheless, I can recall three cases, and doubtless there are others that I have not followed as closely, in which the discarge persisted for monts; in two of them for over a year before it subsided. These patients, although completely relieved of the symptoms for which they had received the treatment, were so distressed by the intractable leucorrhea that they keenly regretted not having submitted to a hysterectomy."

"I know of no way by which this postradial leucorrhea may be prevented, nor by which it may be stopped if it is persistent. I usually perform a thorough curetting before applying the radium on the theory that it may diminish the amount of local necrosis, but whether this makes any material difference I am unable to say."

"PAIN. Pelvic pain has been described by some as one of the typical symptoms following the radium treatment. I have occasionally heard complaints, on the part of my patients, of a slight nagging pain in the side, usually on the left, which has subsided in t few days and has given no further trouble. In a small number of cases patients suffered pain of the radium application, the result aparently of a reaction on the part

of the uterus to a foreign body within its cavity. In a few other cases, however, the pain experienced during the immediate convalescence proved to be the forerunner of later very serious inflammatory consequences. In the light therefore of present experience I am convinced that in the properly selected cases there should be no adnexal pain and that if it does occur, it must be regarded as a danger signal of grave import.

"Too great emphasis cannot be laid on the danger of making intrauterine radium applications in the presence of pelvic inflammation. Even though the active inflammatory process existed years before and there remains only a few peritoneal adhesions radiation is attended with risk. Inasmuch as an old inflammatory process is sometimes missed both in the history and with the most expert preliminary pelvic examination, it stands to reason that even with great care occasional untoward results are sure to be encountered; and anyone who says that the intrauterine application of radium for bleeding is attended with no danger knows little whereof he speaks."

"The injurious influence of radium on chronic inflammatory pelvic conditions, is perhaps the most important reason why in the extensive clinical use to which radium is destined very soon to be put, its employment, in gynecological practice at least should be limited to responsible and welltrained operators."

"Renal Symptoms. Some mention has been made in the literature of a reaction on the part of the kidneys to radiation. I have had an opportunity of observing, in another clinic, the onset of an acute nephritis following an intrauterine treatment, in the case of an elderly woman who had a cardiorenal history. I have collected no specific data on this point in my series of cases, nor have I seen any systematic report in the literature throwing light on the subject. Nevertheless, there is sporadic evidence that caution should be exercised in treating patients with renal disease."

"Nervous Symptoms. Nervousness symptoms following radiation are of peculiar interest. If the menses are inhibited, hot flushes are common, but not constant. They occur in about the same proportion as after hysterectomy with or without the ablation of the ovaries. Some think they are less intense and annoying, others think they are more so. In my experience I cannot see that there is any marked difference one way or the other. They seem to follow the same law as after radical operations in that they are intensified by complicating discomforts and temporary disappointment over the result of the treatment. The influence of the ovarian secretion is strikingly illustrated in cases where, after a period of amenorrhea, the menses are re-established, with a complete synchronous disappearance of hot flushes. As after hysterectomy, the hot flushes when present are usually amenable to ovarian therapy, preferably in the form of the residue or of the whole extract. Occasionally, however, in a patient with an unstable vasomotor equipment, the socalled ablation symptoms, chiefly in the form of hot flushes, may be extremely severe, persistent, and intractable to endocrine treatment. We have had one such case in which the symptoms have continued unabated for over a year."

"In many cases, happily, hot flushes are entirely absent or quite insignificant, and if there are no disquieting sequelae such patients acquire in time a sense of physical and mental wellbeing that is extremely gratifying. On the other hand, the question has arisen in my mind whether in certain neurotic individuals radium may not exert a specific depress-

ing influence has been suggested in the observation of several cases. One patient, a middle-aged school teacher, intelligent but illbalanced, attempted to describe a peculiar sinister effect which the radium had had on her whole being, physical and mental. Another patient, an apparently normal and selfpossessed woman of forty-seven, told me at the end of a month that she was experiencing a continual sense of panic and apprehension such as she had never before felt, and in this case there had been absolutely no other specific disquieting complication following the treatment. In several cases with or without mental manifestations there has been a rather protracted period of physical depression not to be accounted for by the patient's previous health, nor by the effects of the slight operation. * * * * *"

"It is to be noted that I have observed these nervous symptoms as distinctive sequelæ only in cases in whoich the application has been intrauterine. That is to say, I have not observed them specifically after simple vaginal application for cervical cancer. This is suggestive, but not conclusive evidence that the deleterious nervous effects may be exerted through the agency of the ovaries, which are naturally more susceptible to intrauterine than to vaginal radiation."

"If to the possible specific effect of radiation on the nervous system there is added a delayed convalescence with some of the disturbing symptoms mentioned above, there may result a chagrin and disappointment on the part of the patient which may seriously effect her wellbeing. This outcome is entirely comparable to the occasional ill effects of a hysterectomy, and proportionately as frequent."

"The various points brought out in this paper are presented not for the purpose of depreciating the great value of radium in the treatment of nonmalignant uterine hemorrhage, but rather to warn those who have not yet used it for this purpose that the immediate convalescence from a given treatment is by no means always a bed of roses. It is the wish of the writer to emphasize both to the profession and the laity that radium is a powerful and dangerous agent, and that in certain cases, not always recognizable, its use is attended with the gravest risks. The possibilities of radium for harm have not been sufficiently exploited in the literature, and it is the duty of those who are using it to spread the propaganda of caution, in view of the general and perhaps indiscriminate distribution which radium is inevitably soon to enjoy."

* * * * *

C. G. Darwin. The Structure of the Atom. Nature, 51-54; 81-83; 116-118, Sept. 9th, 16th and 23rd, 1920.

Atomic Number

"The study of the interior structure of the atom was initiated about twenty-five years ago by J. J. Thomson's discovery of the electron. Electrons are particles of negative electricity of charge 4.77×10^{-10} electrostatic units and mass 9.0×10^{-28} gr., and they were shown to be constituents of every type of matter. Some years previously Thomson had shown on theoretical grounds that any charged body should possess extra mass on account of its charge, and these two facts taken together suggested the possibility of an electrical theory of matter, whereby all mass should be electromagnetic in origin, and all the properties of matter should be reproduced by the interactions of electrons and positive charges, the latter at that time quite unknown. It is not possible to dwell here on the earlier atom models (such as those of Thomson or Ritz) which were devised on these lines. They had a certain measure of suc-

cess in explaining some of the properties of matter; but we can now see that there was insufficient experimental knowledge at that time, and also that no theory could possibly work which was based on the old classical ideas of dynamics, as these are certainly inadequate to deal with atomic problems."

"As electrons were known to be common to all matter, it was natural to ask how many were contained in each type of atom. The mass of an electron is about 1/1840 of that of a hydrogen atom, and therefore this atom cannot contain more than 1840 electrons. For other elements the corresponding upper limit is given by multiplying the atomic weight by 1840. Thus in all cases a very wide field of choice is left. The attack on the problem was not possible until the development of X-rays and radio-activity had reached a certain stage of advancement, for ordinary chemical and physical methods are quite incapable of penetrating beyond the surface layers of the atom, whereas both X-rays and the radio-active particles are so powerful that they can go right through the atom, and from their behavious in passing we can deduce a certain amount about its interior. With both the method consists in observing the phenomenon of scattering; that is to say, a narrow parallel beam is sent through a plate, and the amounts are found which are thrown off at various angles. Theory tells us how much a single electron should scatter, the number of atoms in the plate is known with some accuracy, and so we can count the number of electrons in each atom, if we assume that the scattering is due to them alone. When this method is applied with either X-rays or beta-particles (the latter are simply electrons moving at a high speed), certain theoretical complications make the results rather inaccurate, but in both cases the experiments clearly indicated that the number of electrons in the atom was of the same general magnitude as the atomic weight. This was found for several elements ranging in weight between carbon and gold. So our first upper limit to the number of electrons in the atom was vastly in excess, and no considerable fraction of the mass of an atom is contributed by its electrons."

"The experiments with alpha-particles were far more definite. An alpha-particle is simply a helium atom, carrying a positive charge equal to that of two electrons, and moving at a very high speed. As the atomic weight of helium is 4, it is seven thousand times as heavy as an electron. When an alpha-particle passes an electron the attractive force sets the electron in motion, and the reaction of this force gives the alpha-particle a small deflection and reduces its velocity slightly. On account of the smallness of the effect of a single electron, great uniformity is obtained in the average, and the number of electrons in an atom can be counted by observing either the scattering of the beam or else the rate at which the particles lose their velocity. Both give the same result, that the number of electrons in an atom is approximately half its atomic weight."

"But the experiments on the scattering of alpha-particles contained the germ of far more important information. For in the course of them it was observed that a certain small fraction of the alpha-particles underwent large deflections. A few even were thrown right backwards. Now this fraction, though small in itself, was out of all proportion large compared with what could be given by the cumulative effect of a large number of collisions with electrons. Rutherford showed that the only reasonable hypothesis to account for this type of scattering was to suppose that the large deflections were produced in a single step. In this way he was led to put forward the nucleus theory of atom, now uni-

versally accepted. According to this theory practically the whole mass of the atom is carried by a nucleus of very small dimensions (at most 10^{-12} cm.) which has a charge of positive electricity equal to some multiple of the electronic charge. This nucleus is surrounded by a cloud of electrons of just such a number as to neutralise its charge. Each element has a different nuclear charge, and (to anticipate some results that we shall come to later) the value of this nuclear charge completely determines all the chemical characters of the element. Radio-active properties belong to the nucleus, as well as mass, while chemical and spectroscopic properties are attributed to the electrons of the cloud, and are only indirectly controlled by the nucleus because it determines the number and arrangement of these surrounding electrons. The dynamical structure of this planetary system was left unspecified, and remains to this day almost unknown."

"Now consider the bearing of this theory on the question of scattering. The alpha-particle is itself the nucleus of a helium atom. In passing through matter most of the particles will not go very near any nucleus, and so will behave in the way we have already discussed. But the paths of a few will take them near some nucleus, and large repulsive forces will be developed between the two positive charges. Most atoms are much heavier than alpha-particles, and so the latter will describe hyperbolas according to Newton's laws, and pass off in new directions. It is a simple matter to calculate the number of particles to be expected at any inclination to the original beam in terms of their initial velocity and the charge on the nucleus. The comparison with experiment, therefore, first furnishes a test as to whether the law of force has been taken correctly, and then provides a value for the nuclear charge. In both particulars the experiments fully bore out the prediction, and it was found that the nuclear charge (measured with the electronic charge as unit) was about half the atomic weight for the lighter elements, and rather less than half for the heavier.

"This method of determining the number of electrons in the atom is by far the most direct yet devised, as the interpretation of the experiments does not involve the rather difficult averaging necessary for the compound scattering produced by the electrons."

"Now if we make a table of all the elements arranged in order of atomic weights, as is done by chemists for the study of the Periodic Law, and if we number them in this order, starting with hydrogen at 1, helium at 2, and so on, it will be seen that the resulting numbers are always in the neighborhood of half the atomic weight. The nuclear charge is by hypothesis some multiple of the electronic charge, and by experiment is about half the atomic weight, and so we are almost forced to suppose that the ordinal number of an element in the table is the same as the number of electronic charges on its nucleus. We do not anticipate an exact correspondence throughout the table, because there may be (and in fact are) gaps in it which represent hitherto undiscovered elements. But apart from this we arrive at the conception of an atomic number for each element. The atomic number of an element is defined as the number of positive electronic charges carried by its nucleus, or, which is the same thing, as the number of electrons surrounding this nucleus."

"It would involve very prolonged work to get the atomic numbers accurately by direct experiment with scattered alpha-particles. Fortunately, this is not necessary, as there exist much more convenient indirect means of determining them. The invention of a powerful

TABLE OF ATOMIC NUMBERS OF THE ELEMENTS

	Hydrogen **1.** H, 1·008 1·008									
Helium **2.** He, 4·00 4	Lithium **3.** Li, 6·94	Beryllium **4.** Be, 9·1	Boron **5.** B, 10·9 10, 11	Carbon **6.** C, 12·00 12	Nitrogen **7.** N, 14·01 14	Oxygen **8.** O, 16·00 16	Fluorine **9.** F, 19·00 19			
Neon **10.** Ne, 20·2 20, 22	Sodium **11.** Na, 23·00	Magnesium **12.** Mg, 24·32	Aluminium **13.** Al, 27·1	Silicon **14.** Si, 28·3 28, 29	Phosphorus **15.** P, 31·04 31	Sulphur **16.** S, 32·06 32	Chlorine **17.** Cl, 35·46 35, 37			
Argon **18.** A, 39·88 36, 40	Potassium **19.** K, 39·1 Copper **29.** Cu, 63·57	Calcium **20.** Ca, 40·07 Zinc **30.** Zn, 65·37	Scandium **21.** Sc, 44·1 Gallium **31.** Ga, 69·9	Titanium **22.** Ti, 48·1 Germanium **32.** Ge, 72·5	Vanadium **23.** V, 51·06 Arsenic **33.** As, 74·96 75	Chromium **24.** Cr, 52·0 Selenium **34.** Se, 79·2	Manganese **25.** Mn, 54·93 Bromine **35.** Br, 79·92 79, 81	Iron **26.** Fe, 55·85	Cobalt **27.** Co, 58·97	Nickel **28.** Ni, 58·68
Krypton **36.** Kr, 82·92 78, 80, 82, 83, 84, 86	Rubidium **37.** Rb, 85·45 Silver **47.** Ag, 107·88	Strontium **38.** Sr, 87·83 Cadmium **48.** Cd, 112·4	Yttrium **39.** Y, 88·7 Indium **49.** In, 114·8	Zirconium **40.** Zr, 90·6 Tin **50.** Sn, 118·7	Niobium **41.** Nb, 93·5 Antimony **51.** Sb, 120·2	Molybdenum **42.** Mo, 96·0 Tellurium **52.** Te, 127·5	— **43.** Iodine **53.** I, 126·92	Ruthenium **44.** Ru, 101·7	Rhodium **45.** Rh, 102·9	Palladium **46.** Pd, 106·7
Xenon **54.** Xe, 130·2 128, 130–1–3–5	Cæsium **55.** Cs, 132·81 Samarium **62.** Sa, 150·4 Thulium **69.** Tu, 168·5 Gold **79.** Au, 197·2	Barium **56.** Ba, 137·37 Europium **63.** Eu, 152·0 Ytterbium **70.** Yb, 173·5 Mercury **80.** Hg, 200·6 197–204	Lanthanum **57.** La, 139·0 Gadolinium **64.** Gd, 157·3 Lutecium **71.** Lu, 175 Thallium **81.** Tl, 204·0 IV.	Cerium **58.** Ce, 140·25 Terbium **65.** Tb, 159·2 Keltium **72.** Kt Lead **82.** Pb, 207·2 XI.	Praseodymium **59.** Pr, 140·6 Dysprosium **66.** Ds, 162·5 Tantalum **73.** Ta, 181·5 Bismuth **83.** Bi, 208·0 V.	Neodymium **60.** Nd, 144·3 Holmium **67.** Ho, 163·5 Tungsten **74.** W, 184·0 Polonium **84.** VII.	— **61.** Erbium **68.** Er, 167·7 — **75.** — **85.**	Osmium **76.** Os, 190·9	Iridium **77.** Ir, 193·1	Platinum **78.** Pt, 195·2
Emanation **86.** III.	**87.**	Radium **88.** Ra, 226·0 IV.	Actinium **89.** Ac II.	Thorium **90.** Th, 232·15 VI.	U.X$_{II}$ **91.** II.	Uranium **92.** U, 238·2 II.				

The atomic numbers were mostly fixed by the less direct method of Moseley, which will be described later. For convenience the "isotopes" (also to be discussed later) are given in the table. Thus as an example, read:—Chlorine, atomic number **17,** symbol Cl, atomic weight by chemical methods 35.46, composed of two isotopes 35 and 37. In the case of the radio-elements **(81-92)** the evidence is of a different kind, and the roman numeral gives the number of them believed to exist. The nomenclature of some of the rare earths **(69-72)** is not yet standardized. The names here are those used by Moseley. Some of these elements, though detected by their X-ray spectra, have never been isolated. As points of some interest, observe that in three cases (A and K, Co and Ni, Te and I) the order of atomic weights is wrong, while the periodicity of the chemical properties corresponds to the atomic number. Observe also the five missing elements—**43, 61, 75, 85, 87;** the properties of which can be predicted with fair confidence from the Periodic Law. A curious relation, pointed out by Rydberg, is that the atomic numbers of all the inert gases are given by taking the series $2(1^2+2^2+2^2+3^2+3^2+4^2+\ldots)$ and stopping the summation at any term.

method of studying X-ray spectra enabled Moseley to examine the spectra from a sequence of elements. Whereas visual spectra have a highly complicated structure, and exhibit the same periodicity as do chemical properties, for the X-rays this periodicity disappears, and is replaced by a perfectly orderly progression from element to element. Each spectrum can be derived from the last by a reduction of the wave-lengths according to a simple rule. Thus an examination of a sequence of spectra reveals the true order of the elements, and gaps are shown by a missing term in the sequence. It will be seen that Moseley's method only gives differences of atomic number, and not the numbers themselves. To determine these we must find one of them in some other way. This is not difficult, for we know from observation on alpha-particles that helium must have atomic number 2; and though X-rays have not been observed for the first dozen elements, the periodic table is perfectly regular in that region, and it is impossible to believe that it could contain any gaps. More remarkable still, if the formula for the wave-length of the X-ray spectrum is extrapolated right back to hydrogen, it reproduces the fundamental line of the famous Balmer series. The numbers which were given in the table are therefore certainly correct."

"In formulating the principle of atomic number we said that it, and not the weight, completely determines the chemical character of the element. This statement is justified by a line of evidence which we must now consider. The process of radio-active transformation consists in the emission of an alpha- or a beta-particle from the nucleus, and this emission transmutes the atom into a new element. From a study of the chemical behaviour of these successive elements it was concluded that the emission of an alpha-ray shifts the element two places to the left in the periodic table, while the emission of a beta-ray shifts it one place to the right. This fits in exactly with the conception of atomic number, for when the nucleus loses an alpha-particle (that is, a helium nucleus of atomic number 2) its own number must be reduced by two, whereas the loss of a beta-particle out of the nucleus must raise the number by one, since the beta-particle is an electron and has a negative charge. By a study of all the radio-elements we can work out chains of transformations such as are shown in Fig. 1. These chains start at uranium 92 and thorium 90, and, so far as we know, all end at lead 82. It will be seen that most of the numbers are occupied several times over. For example, 90 has ionium, the parent of radium, as well as thorium and several others. It has been found that the spectra of ionium and thorium are exactly the same, and that all chemical methods are quite powerless to separate them from each other. They are chemically identical because they have the same atomic number, but they differ in the nature of their nuclei, as witnessed by the difference in their radio-active behaviour. Such substances are called *isotopes*."

"The existence of isotopes was first proved from radio-active evidence. But besides possessing the radio-active characteristics of the atom, the nucleus also carries its mass, and this sugget that isotopes may differ in mass. The first evidence for this can be derived from the study of the figure. For example, uranium at 92 loses an alpha-particle and two beta-particles, and thus returns to 92; and the loss of the particles must have reduced its weight from 238 to 234. The same principle has been experimentally verified by finding that the atomic weight of lead from radium is perceptibly different from that of ordinary lead. We shall see in the next article that ordinary elements also have isotopes;

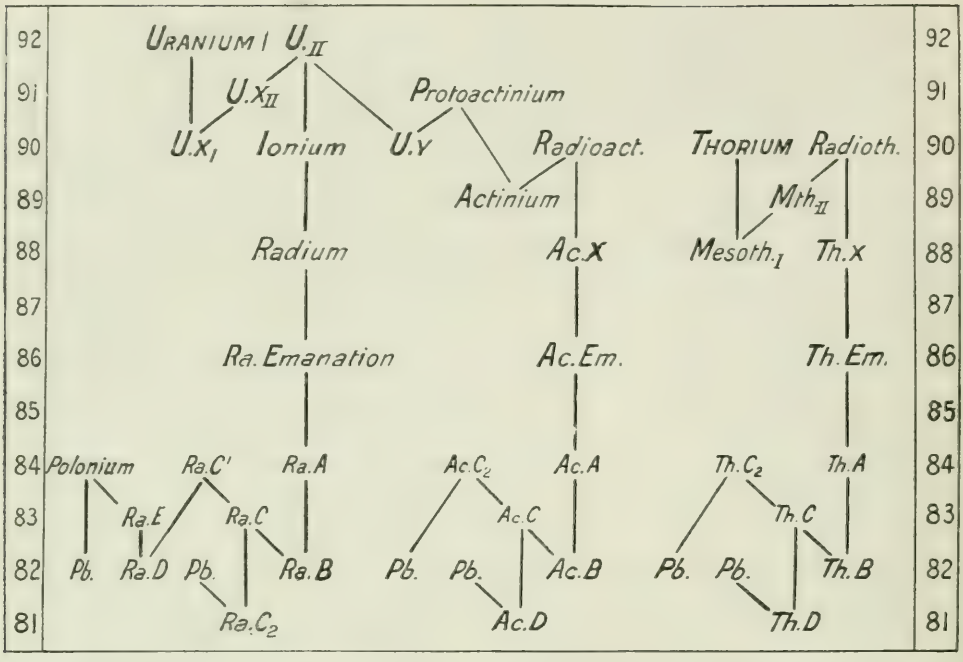

FIG. 1—The Radioactive Transformations. In every case a step two downwards is accompained by the emission of an alpha-particle, and one upwards by a beta-particle. Actinium is derived from uranium or an isotope, but the connection shown is rather conjectural. Thorium C has a third branch about which little is known. The final products in all cases are believed to be lead, but as they are not radio-active it is uncertain how many of the isotopes are really different. In the Table of Atomic Numbers they were counted as all different, and one was added on to allow for the existence of common lead. One was also added there for 81 and 83 to represent the non-radio-active types of thallium and bismuth.

for convenience, these have been given in the table, in so far as they have been yet discovered. It should perhaps be here mentioned that the mere difference of atomic weight theoretically implies certain minute differences in chemical behavious, but it can be shown that these are out of all proportion less than those between substances of different atomic number, so much so that it is an almost impossible laborious task to separate isotopes by ordinary chemical or physical processes."

"The general outcome of our argument has therefore been that atomic number, and not atomic weight, is the determining factor in the behavour of an element. There are exceptions to this rule—for example, specific heat depends directly on the weight of the atom—but apart from these exceptions the importance which in the past the chemist and spectroscopist have given to atomic weight must in the future be attached to atomic number."

The Nucleus

"In the previous articles we discussed the nucleus mainly in connection with the idea of atomic number. We shall now return to the characters of the nucleus itself; but before doing so it is necessary to say something about the atom as a whole. Comparatively little is known about the electrons surrounding the nucleus—it is not even universally agreed whether they are at rest or in motion—but a successful beginning has been made by the Bohr spectrum theory, which applies mainly to the specially simple case of hydrogen. On the same lines Sommerfeld has also had some success with the X-ray spectra. It is quite cer-

tain, as in all questions of atomics, that the laws of classical dynamics do not hold, and the principal method in research at present consists in a judicious mixture of these laws with the quantum theory. This latter theory is definitely contradictory not only to the laws of mechanics, but also to almost any conceivable modification of them, and its chief justification, an entirely adequate one, is the astounding success with which it has been extended over more and more branches of physics."

"We shall not deal here with these spectroscopic questions, but it will be convenient to have a definite idea of the scale on which the atom is built. The proportions of its parts vary over so wide a range that no drawing can possibly represent them. We shall be dealing with magnitudes as small as 10^{-16} cm., and as these large negative indices convey little definite to the mind, it will be convenient in describing the atom to raise the whole scale by 10^{13}. On this scale 1 cm. would become a length about two-thirds of the distance from the earth to the sun. The outermost electrons of the atom would be about a kilometre from the nucleus, and for the heavier elements the innermost, perhaps three in number, would be roughly 10 metres from it. As to the nucleus itself, there is definite evidence that it is less than 30 cm. in radius, and, in some cases at any rate, that it is greater than 2 cm. Other physical quantities which we shall require are of a slightly more hypothetical nature. On the theory that all mass is electromagnetic, we can calculate the radius of an electron, since we know its charge and mass. This radius comes to about 2 cm. (actually 1.88×10^{-13} cm.). By a similar calculation the hydrogen nucleus has a radius of about one-hundredth of a millimetre. The same argument would make the radii of heavier nuclei about as small as this, but would not be justifiable, because, as we shall see, there is clear evidence that these nuclei owe their large mass to their being composite structures built up from hydrogen nuclei and electrons. From the extraordinary smallness of the quantities we have considered, it is not surprising that experiments with the nucleus should be very difficult. We now turn to these experiments."

"When first describing the nucleus, in the first article, we saw that when an alpha-particle goes near it, it describes a calculable orbit, so that we can find a distance of closest approach between the two. As the predicted law of scattering was borne out by experiment, we can conclude that the law of force at this distance of closest approach (3×10^{-12} cm. for gold, above called 30 cm.) is still the inverse square law. Therefore the sum of the radii of the alpha-particle and the nucleus must be less than this. But a different case has been studied in great detail by Rutherford. Where the alpha-particles are passing through hydrogen, the repulsive forces between the nuclei are much weaker than for other substances, because the atomic number of hydrogen is only 1, and so the nuclei can get much closer together. But there is also another difference, for the hydrogen nucleus has mass only a quarter of that of the alpha-particle. Consequently, if there is a "straight on" collision the hydrogen is shot forward at a speed higher than that of the colliding alpha-particle, and the latter follows on behind with reduced speed. This new type of particle, the H-particle, then proceeds to traverse any matter in its path, losing speed in the same sort of way as does an alpha-particle, and it can be calculated that, whereas the fastest alpha-particles go through only 7 cm. of air, the fastest of these H-particles should go through 28 cm. Experiment bore out this prediction, but when the calculation was pushed further so as to show how many should go various distances from 28 cm, downwards, a very wide difference was found

between theory and experiment. This indicates that there is something wrong with the theory—in fact, that the approach between the nuclei is so close that the ordinary law of repulsion fails. This ordinary law would give 2×10^{-13} cm. as the distance of closest approach, and we therefore conclude that the sum of the radii of the hydrogen and helium nuclei is greater than this. Now the radius of the electron is about 2×10^{-13} cm., and the coincidence of these two numbers tends to support the view that there are electrons in the nucleus of the helium atom."

"Turning now to the constitution of the nucleus, the first piece of information is provided by radio-activity. In successive radio- active transformation alpha- and beta-particles are projected from the nucleus. Therefore the latter must contain both — that is, helium nuclei and electrons. Next we have the evidence from Rutherford's transmutation of elements. The experiments in which this occurred consisted in the bombardment of various elements by alpha-particles. When nitrogen was tried, he observed that a certain number of H-particles was obtained. As no hydrogen was present, we are compelled to conclude that these particles were knocked off the nuclei of the nitrogen atoms; so we can be confident that these nuclei contain hydrogen nuclei. In recent work Rutherford has got even further, for he has found another entirely new type of particle which is sometimes knocked off nitrogen and oxygen. These particles have atomic mass 3 and number 2, so that if they were obtained in bulk they would be helium of density 25 per cent. less than ordinary helium. It is at present unknown what happens to the remainder of the nucleus after these losses. A point of great interest in this work is that the new particles come off with greater energy than that of the bombardming alpha-particles. If we carry over the language of chemistry to this new domain we should say that the reaction is exothermic, and nitrogen in a metastable state."

"We have so far discussed the special properties of particular elements. The next evidence is very much more general, and holds out great promise of extension. This is the recent work of Aston with the "positive rays." It was undertaken in order to detect whether ordinary elements wer composed of isotopes. He found that this was true of the majority of those he examined (his numerical results are given in the table in the first article), but the important result from our present point of view is that in all his elements the atomic weight of each isotope was almost exactly in integer. This will be slightly qualified in the next paragraph. Aston has so far examined eighteen elements and found the rule true, and it is scarcely credible, therefore, that it should not be universal. But if so, it can only mean that all nuclei are constructed out of hydrogen nuclei. That would satisfy the conditions as to mass, and in order to make the atomic number correct we must then suppose that these hydrogen nuclei are cemented together by electrons. For example, chlorine has atomic number 17. Its atomic weight, determined chemically, is 35.5, and Aston finds that it is composed of two isotopes at 35 and 37. Therefore three-quarters of the chlorine atoms have nuclei composed of 35 hydrogen nuclei and 18 electrons, while for the remaining quarter the numbers are 37 and 20 respectively. This is the revived form of the famous hypothesis of Prout."

"Aston's experiments have not hitherto been sufficiently accurate to detect any departures from the whole number rule, except in the case of hydrogen. In this case his work confirms the chemical result that the atomic weight is 1.008 instead of being 1. At first sight this would appear to dispose entirely of the validity of our interpretation of the whole

number rule, but that is not so, and by the use of arguments based on the work of Einstein on relativity, the departure from whole numbers can be made to yield valuable information. Einstein's theory implies that all energy must have mass (and also that all mass must have weight). Thus the mass of a helium nucleus (at. no. 2 and at. wt. 4) will not be simply the sum of the masses of its four alpha-particles and two electrons, but will also include the mass of its energy of formation. As the helium is lighter than the sum of the weights of these particles, we conclude that this energy is negative—that is to say, an atom of helium has less energy than its separated particles. Lenz has calculated the difference and finds that it corresponds to the energy of about three of the fastest alpha-particles. So helium is an exceedingly stable substance, and it need create no surprise that its nuclei, when projected as alpha-particles, can undergo the most violent collisions without disruption. It also makes it not unnatural that in radio-active disintegration it is helium, and not hydrogen, that is emitted. Moreover, it is well known that the atomic weights of most elements are nearer whole numbers when helium is taken as standard at 4 than when hydrogen is taken at 1. This indicates that in most atoms the majority of the hydrogen nuclei are bound together in helium sub-groups.

"It will thus be seen that a very promising beginning has been made in the study of the nucleus. We know that it is built up of hydrogen nuclei and electrons, and that there is a strong tendency to form helium sub-groups. We know the number of hydrogen nuclei and electrons in the nuclei of many of the elements, and may expect to know those of the majority at no distant date. Most encouraging of all, we may hope that it will not be very long before a definite theory of the structure of nuclei is made, based on exact knowledge of the energy of formation of the various elements."

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John S. Shearer, Ph. D. (Ithaca, N. Y.). The Physics of the Roentgen Ray. Arch. of Derm. and Syph. xxxviii, 664-680, June, 1920.

In this article Professor Shearer gives a very clear discussion of the nature of the X-rays, their production, absorption, action, etc. A number of paragraphs from the article are here quoted.

"The increasing use of roentgen rays in the treatment of cutaneous diseases make the fundamental laws of their production and their physical characteristics of more than passing interest. That the busy practitioner cannot spend the time to become a trained physicist is obvious, but it is equally certain that some general ideas may be of value in the selection of apparatus and in the rational use of the roentgen ray. While a single, brief article cannot fully serve this purpose, it may be of service in presenting the main physical features."

"Roentgen rays are one manifestation of what the physicist refers to as energy of radiation, of which light and radiant heat are the more generally known. These radiations are originated by some disturbance of the minute parts of which matter is composed, i. e., of molecules, atoms or of subatomic bodies called electrons. The latter have borne various names during the development of modern views on electricity, such as cathode rays, beta rays, etc. They play an important part in all physical phenomena, especially in roentgen rays and in radio-activity."

"It may be well to state that the term ray is used to indicate two unlike classes of physical phenomena in both physics and medicine. In one class small particles of definite size and properties are projected from

matter into the surrounding space. Thus, when an atom of radio-active matter breaks down there may be projected alpha particles or rays, beta particles or beta rays. These differ in size and electrical quality as well as in velocity. They are concrete entities that may be counted and studied as individuals. Again we use the term ray to define the path along which some wave-like disturbance travels as in the case of light rays, heat rays, roentgen rays and gamma rays, where no transfer of matter is involved."

"A bullet dropped on the surface of still water might, if we wished, be called a lead ray and the radii of the spreading waves system set up could be named some sort of rays, but they would only indicate a direction of wave propagation not material. In the case of sound the direction along which sound is received might be called a sound ray, but no projectile is involved."

"While sound requires a tangible material for its propagation, such as air, wood, water, etc., light, while originating in some substance may be propagated through the most complete vacuum. Experiments have shown conclusively that light is due to electromagnetic actions and originates in the disturbance of the electrical components of atoms. The same is true of roentgen rays and gamma rays which, like light, are not corpuscular or due to projected particles, but are real electromagnetic waves. We may compare sound and light roughly as follows:

COMPARISON OF SOUND AND LIGHT

	Sound	Light
Source	Material vibrating bodies...	Vibration of parts of atoms far too small for microscopic vision
Frequency	From 30 per second to a few thousand per second	Of the order 100 million million per second
Wave length	A few inches to several feet.	Expressed in hundred millionths of a centimeter
Velocity	About 1,200 feet per second..	About 186,000 miles per second
Composition gives.	Quality	Color value

"Roentgen rays in turn differ greatly from light waves. Their vibration frequencies are even greater and their wave lengths much shorter; their velocity of propagation and origin are, however, the same as for light."

"In measuring wave lengths of light the Aengstrom or 1/100,000,000 cm. is usually chosen as a unit. The wave length of yellow light from sodium vapor is about 6,000 of these units, while roentgen ray wave lengths would be expressed by fractions of an Aengstrom.* Thus we have the diameter of a hair, 0.002 cm.; wave length of yellow light, 0.00006 cm.; medium roentgen-ray wave length, 0.000000005 cm.

"It is, then, clear that these waves are of exceeding "fineness of grain," if we may use a common term. The distance between atoms in crystals of metals is from 2 to 4 Aengstroms, so that such atoms are separated by a distance equal to several wave lengths of roentgen rays such as are commonly used. It may readily be seen how the behavior of such waves would be differently affected by matter than would long ones."

*Note—The hard x-rays have a wave length of the order of 0.1 Angstrom. The hard gamma rays have a wave length estimated of the order of 0.001 Angstrom. X-rays of this hardness might be produced if a difference of potential of one or two million volts were applied to an x-ray tube. This would correspond roughly to spark, gaps of 8 to 17 feet, as against the 10-inch spark gaps now used for deep x-ray therapy.—Ed.

"The origination of such minute waves is due to disturbance of electrons. These consist of, or else carry at all times, a definite electric charge. They are essential elements in the structure of all atoms, and may be torn out of any atom by suitable physical agencies. They are much smaller than the atoms of any known element. For our purpose only two means of separation of electrons from matter need be mentioned: these are (1) the breakdown of gas molecules in a vacuum tube, (2) their shaking out from the atoms of a very hot metal. The first serves for the operation of the older type of gas tube, the second is used in the Coolidge tube."

"We have a great variety of experiments showing that only when the velocity of electrons is suddenly changed do we get the short electromagnetic waves known as gamma rays or roentgen rays. The former are due to the sudden starting of electrons by the explosive breakdown of atoms, the latter to the reduction of velocity by impact on an obstacle."

"In the operation of a roentgen-ray tube, electrons in enormous numbers are separated from atoms and by reason of their electric charges are given almost unbelievable speed and strike the hard metallic surface of the anode or target with the result described above. For a target of given material (tungsten is now almost exclusively used), only two operating factors need concern the therapeutist. The nature and the quantity of radiation is absolutely fixed by the number of electrons used per second and their striking speed . A properly calibrated milliameter tells the relative number of electrons and the electric difficutly of driving them through the tube indicates their speed. The latter might be measured by suitable electric instruments (volt meters) or spark gap meters, but those hitherto provided are not generally reliable, so we offer the electric stream an opportunity to pass around the tube between two adjustable points constituting a spark gap."

"We may now consider what meaning should be attached to the terms quantity and quality. Since we have no special sense organs that enable us to see by roentgen ray brightness or recognize anything comparable to color in light, we must derive our information in other ways. The quantity of light from a given source might be found by allowing it to be transformed into heat and measuring the latter, but we should find that such a measure would not be comparable with that made by using some other effect due to light."

"The following effects due to roentgen rays have been used as a measure: (1) The photographic effect; (2) color change in certain chemicals; (3) separation of electrons from atoms (ionization) (photo electric action, etc.), and (4) heat produced when absorbed. But as in the case of light the results of such measurements are not always comparable. At present even the radiation from light sources is measured by observing the factors governing production. Thus an incandescent lamp of 20 candlepower is of that power only when operated at a given voltage, so that it carries a specific current. We may well come to measure roentgen rays in the same terms."

"Some difficulty is experienced by many readers as to the significance of the term "secondary" rays, and in fact the term has been used to specify at least three different things, for which other terms might better be used."

"1. Roentgen rays coming from parts of the tube other than the focal spot; these may be better designated as parasitic rays."

"2. Atoms of matter reflect roentgen rays slightly just as particles of dust or mist will reflect light. This results in a slight diffuse scatter-

ing of the initial beam without other change. If we could secure a surface made up of a closely packed layer of completely reflecting atoms we would have a roentgen-ray mirror. As there are no such atoms or any surface of such smoothness and compactness we have only scattering."

"3. Also when roentgen rays of sufficiently short wave length (due to proper high voltage operation) strike certain atoms, the original beam may give rise to a new beam whose quality depends on the atomic weight of the affected atoms. These are true characteristic secondary rays. They interest the therapeutist in some cases. If thin metal filters are close to the skin and receive enough roentgen rays of short wave length, the characteristic easily absorbed long wave length radiation may injure the skin. Also when metallic ointments or medication are present in the tissue the true characteristic may give undesired results."

"The general facts stated above may be summarized for application thus:

"1. The electrical conditions of operation fix absolutely the radiation delivered per second by a given target; hence adequate control of these conditions will enable complete duplication of radiation both in amount and quality."

"2. The two factors to be noted are: (a) Spark gap or tube voltage; (b) current in milliamperes. Of these, the former is by far the more important.

"3. The amount received by a given layer of tissue when the tube is operated for a definite time under prescribed electric conditions depends on two things; (a) The distance from the target; (b) the nature and thickness of all material through which the rays have passed before reaching the tissue treated."

"4. The reaction to roentgen rays by living tissue is due to rays absorbed."

"5. There is no evidence at present that the biologic effect depends on the particular wave lengths absorbed."

"6. The biologic effect doubtless depends not only on the total amount absorbed, but to some extent on the rate of absorption; in other words, on the frequency of treatment as well as on the quantity of radiation."

"7. Layers of tissue near the surface of entrance always receive and absorb more radiation than the deeper layers."

"8. The inequality of absorption between deep and surface layers due to decrease of intensity with distance is reduced by increasing the distance of the tube from the skin."

"9. The inequality of dose between different layers is reduced by the use of filters."

"10. This inequality is also reduced by operating at a moderately high voltage."

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